THE INTELLIGIBILITY OF HYDROGEN-SPEECH AT 200 FEET OF SEAWATER EQUIVALENT

by

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SUMMARY PAGE

THE PROBLEM

To evaluate the effect of a hydrogen breathing mixture on the intelligibility of a talker's speech.

FINDINGS

Mean intelligibility scores at a simulated depth of 200 feet of salt water were approximately the same for speech produced breathing 97 per cent helium or 97 per cent hydrogen mixtures. The speech production in both gas mixtures was approximately 35 percentage points less intelligible than speech produced in air at one atmospheric pressure (1 ATA) and 25 percentage points less than speech produced in air at 7 ATA.

APPLICATION

Information contained in this report is useful to the design of communication systems intended to improve production of speech by divers during deep-submergence operations.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Bureau of Medicine and Surgery Work Unit M4306.03-2020D - Evaluation of Underwater Communications Systems for Navy Divers. The assistance of Dr. Harry Cooker was furnished under ONR Contract with the University of Connecticut (N00014-67-A-0197-0001). The present report is No. 9 on this Work Unit. It was approved for publication on 1 March 1972, and designated as Naval Submarine Medical Research Laboratory Report No. 701.

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ABSTRACT

The purpose of this study was to evaluate the effect of breathing hydrogen on the intelligibility of speech. Taped recordings were made of a talker breathing normal air within one atmospheric pressure absolute (ATA) and also breathing successively, hydrogen, helium, and air, at 7 ATA. Responses to the recordings by six panels of listeners were analyzed. As expected, the speech in air at 1 ATA was the most intelligible, and the speech in air at 7 ATA was next best. There was no appreciable difference in mean intelligibility between the helium and hydrogen gas mixtures. These results indicate that any decision in favor of using either hydrogen or helium mixtures in deep sea diving should not depend upon differences in intelligibility of unprocessed helium - versus hydrogen-speech.

THE INTELLIGIBILITY OF HYDROGEN-SPEECH AT 200 FSW EQUIVALENT

INTRODUCTION

This and other laboratories have considered the effects upon speech intelligibility of different gas mixtures which might be used by deep sea divers[8]. The simple effects of breathing helium-mixtures are striking. In addition to obvious changes in the quality of the speaker's voice, the intelligibility is reduced, especially under the restraints of hyperbaric environments. Theoretical explanations of helium-speech lead one to conclude that intelligibility would be even more seriously affected if divers breathed mixtures rich in hydrogen.

At the present time very little is known about the physiological effects of breathing hydrogen-oxygen (hydrox) mixtures. Although hydrogen is available in large quantities (i.e., H_2O), most researchers shy away from the mixture due to the extremely high possibility of explosion. Edel[1] points out that under hyperbaric conditions the amount of oxygen required for breathing by the diver can be made small enough to eliminate hazards of explosion for hydrox mixtures. It seems plausible to him that hydrogen could be the common breathing mixture used in dives at levels deeper than 200 feet. If the disadvantages of decompression requirements, bends, and other physiological factors, which are present with diving gases currently in use, do not exist or are less for hydrogen-rich mixtures, then hydrogen might well replace helium as the deep sea diver's desired breathing mixture at great depths. One of the primary considerations in the decision to use hydrox mixtures would be the effect it has on diver communication by voice.

The purpose of the present study was to evaluate the effect of breathing hydrogen on the intelligibility of speech.

PROCEDURE

Tape recordings were made of speech produced while the talker breathed air at 1 ATA and air, hydrogen, and helium mixtures compressed to 7 ATA during an experimental dry chamber dive conducted at the J & J Marine Diving Company in Pasadena, Texas. Appendix I is the dive-protocol followed during the collection of speech samples. Responses by listening panels to the recordings were later obtained and analyzed.

Recording of Stimulus Material. Recordings were made within a small pressure chamber of several 50-word lists of the Modified Rhyme Test (MRT)[3] using a General Radio 1550-P5 piezoelectric microphone (see Ref. 7 for a description of the characteristics of this microphone under hyperbaric conditions). The recording system included a Uher professional quality portable tape recorder which was outside the chamber during actual recording. An adult male talker read the word lists while sitting inside the chamber. He had received training in reading the intelligibility testing materials prior to the experiment.

The gas mixtures which the talker was breathing when his speech was recorded were as follows:

a) Air at 1 ATA. Immediately prior to pressurizing the chamber, talker breathing normal air mixture assumed to be 80% N_2 and 20% O_2 inside the chamber. Ambient pressure was 1 ATA.

b) Hydrogen. Immediately upon reaching pressure of 7 ATA, chamber atmosphere approximately 97% N_2 and 3% O_2, diver breathing mixture of 97% H_2 and 3% O_2 through oral-nasal mask.

c) Helium. Same conditions as above except breathing mixture in diver's mask changed to 97% He and 3% O_2.

d) Air at 7 ATA. Diver's breathing mixture in mask changed to 80% N_2 and 20% O_2.

Presentation of Stimulus Material to Listeners. Listeners heard the recorded speech in a group audio-testing room that was equipped with 50 matched TDH-39 earphones embedded in circumaural cushions. The stimulus tapes were presented to 90 normal-hearing Navy enlisted men divided into six listening panels of 15 each. Table 1 shows which gas the talker was breathing when he spoke and which MRT List he was reading for each group of listeners. The words were presented at an average level of 75 dB Sound Pressure Level (SPL) to panels 1 through 4, and 65 dB SPL to panels A and B. The output of a Grason-Stadler 901A Noise Generator was combined with the speech signals in order to produce a -10 dB speech-to-noise ratio (S/N). Measurements of SPL at the ear were obtained using a flat-plate acoustic calibration coupler. Listeners responded on IBM answer sheets specially constructed for use with the MRT word lists.[5]

RESULTS AND ANALYSES

Table 1 shows the mean per cent correct responses for each word list. The poorest score was 28% for the helium condition, while the best performance was obtained as expected for the two pre-dive lists when the talker was breathing a mixture of air at 1 ATA. Two basic analyses were performed with the data, one to test the equivalency of listening panels and word lists, the other to consider the effects of breathing mixture on the talker's overall intelligibility.

Listeners and Word Lists. Listeners were randomly selected from Navy enlisted men who had passed the physical requirements for entrance into Submarine Service. In order to assess effects which might have been caused by differences in either the particular panels of listeners tested or the specific 50-word lists used as the testing material, an analysis of variance was made of the responses by listening Panels A and B. The ambient pressure and gas mixture for the talker was identical for these tests, i.e., air at 7 ATA. Results of a Lindquist Type 1 two-factor mixed design[4] indicated that there was no difference (at the 95 per cent level of statistical confidence) between the lists nor between the panels. Interaction between panels and lists also was not statistically significant. We conclude

Table 1. Mean Per Cent Correct Responses by Listening Panels According to MRT List Heard and the Gas Mixture which the Talker was Breathing

Panel	Breathing Mixture	MRT List	Per Cent Correct
A	Air at 7 ATA	E	56
		A	55
B	Air at 7 ATA	E	54
		A	53
1	Air at 1 ATA	B	69
		A	70
2	Hydrogen at 7 ATA	C	38
		A	34
3	Helium at 7 ATA	D	28
		A	35
4	Air at 7 ATA	E	59
		A	59

from these data that analysis of responses by Panels 1 through 4 to the recordings of speech which represents the different types of breathing mixtures could be safely made without undue errors arising from effects of either listening panels or word-lists.

Breathing Mixtures. Table 2 summarizes a Lindquist Type 1 analysis of the responses by Panels 1 through 4. Neither the interaction between gas-mixture and Lists nor the main effects of the MRT Lists were statistically significant. The main effect of the gas mixture on the other hand revealed significant differences ($F = 245$; $df = 3,56$). The mean intelligibility scores in Table 1 show that the speech produced in air at 1 ATA was most intelligible with 69 and 70% correct responses. The responses to speech produced in the hydrogen and helium mixtures under pressures of 7 ATA were equally poor, yielding mean scores ranging from 28 to 38%. The results for speech in air at 7 ATA lie between the higher scores for air at 1 ATA and the scores for the hydrogen and helium conditions at 7 ATA. The difference

between scores obtained for air at 1 ATA and at 7 ATA for Panels 1 and 4 (Speech playback level consistently 75 dB SPL) can be attributed solely to effects of increased ambient pressure upon the intelligibility of the talker's speech. This finding supports other reports[2,9] of deterioration in the intelligibility of speech in air under hyperbaric conditions.

DISCUSSION

The similarity of mean responses for the hydrogen and helium conditions was not expected. Differences between the physical properties of hydrogen and air are in the same direction, but to a much greater degree, than differences between helium and air. For example, the velocities of sound for air, helium and hydrogen are respectively 331, 970 and 1270 meters/sec. Since the quality of helium-speech is noticeably different than the quality of speech in air, it was assumed that the difference in quality for hydrogen-speech would be even greater.

Concentrations of energy around certain frequency areas in a speech signal called "formants" are dependent upon characteristics of the human resonators for speech. One of the basic physical parameters which determines the frequency characteristics of any resonator

Table 2. Summary of Analysis of Variance

Source	df	ms	F-Ratio
BETWEEN SUBJECTS	59	134	
B-Gas Mixture	3	2450	245.3*
Error Term (b)	56	10	
WITHIN SUBJECTS	60	17	
A-MRT Word List	1	11	1.5
AB-Gas/List Interaction	3	42	2.6
Error Term (w)	56	16	
TOTAL	119		

* Significant beyond 99% level of confidence.

is the velocity of sound through the gas that is inside the resonator. Quite probably, the primary effect of both helium and hydrogen gas mixtures on the intelligibility of speech is due to changes in the resonating characteristics of the human mechanism for producing speech. Both helium and oxygen cause an increase in the velocity of sound as compared with the velocity in air, and consequently there is the same type of distortion for both gas mixtures, i.e., an upward shift of the frequency of the formants of speech (see Ref. 6 for a more detailed explanation of relations between breathing mixtures and the resonators for speech). As a result, other clues than frequency characteristics, such as prosodic features and temporal patterns, probably assume more prominent roles in overall talker intelligibility. These results indicate that factors associated with the intelligibility of unprocessed speech should not be used in arguments influencing a decision to use hydrogen in lieu of helium in breathing mixtures for deep sea divers.

Speech produced while the talker was breathing hydrogen or helium was compared in this study from the point of view of overall intelligibility of the resultant unprocessed vocal output. Future evaluations of speech with these gases should (1) relate perceptual aspects of the speech with its acoustic characteristics, (2) specify what particular features of the speech signal can be used to determine how intelligible different talkers are, and (3) evaluate effects of processing upon the intelligibility of speech in hydrogen. The first area would provide information which could help redefine specifications for the design of voice communications systems, including processing devices, for hydrogen and helium atmospheres. The second effort would provide clues which are pertinent to the selection of the best talkers for either gas mixture. The last area for investigation concerns the important question of whether or not the intelligibility of hydrogen speech can be successfully improved with presently available processors which were originally designed for use with helium-speech.

SUMMARY

Tape recordings were made of a talker's speech while he breathed air within 1 atmospheric pressure absolute (ATA) and successively, hydrogen, helium, and then air at 7 ATA. The recordings were later presented to panels of listeners. As expected, the speech in air at 1 ATA was most intelligible, that in air compressed to 7 ATA was next best. There was no appreciable difference in overall intelligibility between the helium and hydrogen conditions but both gases yielded worse intelligibility than air. These results indicate that any decision to use hydrogen or helium mixtures in deep sea diving should not depend upon differences in the intelligibility of unprocessed speech produced therein.

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APPENDIX I

TRI-INERT DIVE

Time (min)	Depth (fsw)	Breathing Mixture	Remarks
-10	0	Air	Final systems checks. Diver enters chamber. Start Pre-dive speech recordings.
-2	0	Air	All cigarettes and open flames extinguished. Stop speech tests.
-1	0	Air	Hatch closed.
0	0	80He-20 O_2	Start compression with N_2 (diver breathing He-O_2)
1/4	25	80He-20 O_2	
1/2	50	80He-20 O_2	
3/4	75	80He-20 O_2	
1	100	97He-3 O_2	Switch to 97% He-3% O_2 (signal diver to vent) 1 rap
1 1/4	125	97He-3-O	
1 1/2	150	97He-3-O_2	
1 3/4	175	97He-3-O_2	
2	200	97H_2-3% O_2	Arrive on bottom; switch to hydrogen-oxygen
3	200	97H_2-3% O_2	Start communications tests
6	200	97H_2-3% O_2	Dr. Alexander enters outer lock
7	200	97H_2-3% O_2	Outer lock door closed

Time (min)	Depth (fsw)	Breathing Mixture	Remarks
8	0 OL	$97H_2$-3% O_2	Start compression with N_2: Dr. breathing 80He-20 O_2
8 1/4	25 OL	$97H_2$-3% O_2	
8 1/2	50 OL	$97H_2$-3 O_2	
8 3/4	75 OL	$97H_2$-3% O_2	
9	100 OL	$97H_2$-3% O_2	Switch Dr. to 97He-3 O_2 (signal one rap for switch)
9 1/4	125 OL	$97H_2$-3% O_2	
9 1/2	150 OL	$97H_2$-3% O_2	
9 3/4	175 OL	$97H_2$-3% O_2	
10	200 OL	$97H_2$-3% O_2	Both locks equalized; stop communication test
11	200	$97H_2$-3% O_2	Dr. Alexander takes blood sample
12	200	97He-3 O_2	Switch diver to 97He-3 O_2
12 1/2	200	97He-3 O_2	Dr. Alexander in outer lock
13	200	97He-3 O_2	Drop outer lock; start purge with N_2
13 1/4	187 1/4 OL	97He-3 O_2	
13 1/2	175 OL	97He-3 O_2	
13 3/4	162 1/2 OL	97He-3 O_2	
14	150 OL	97He-3 O_2	Dr. Alexander shifts to 80 He-20 O_2 (signal one rap)
14 1/4	137 1/2 OL	97He-3 O_2	
14 1/2	125 OL	97He-3 O_2	

Time (min)	Depth (fsw)	Breathing Mixture	Remarks
14 3/4	112 1/2 OL	97He-3 O_2	
15	100 OL	97He-3 O_2	Diver starts He-O_2 speech test
15 1/4	87 1/2 OL	97He-3 O_2	
15 1/2	75 OL	97He-3 O_2	
15 3/4	62 1/2 OL	97He-3 O_2	
16	50 OL	97He-3 O_2	Dr. Alexander arrives at 50 feet. Hold for 1 minute.
17	50 OL	97He-3 O_2	Start Dr. Alexander to next stop
17 1/3	40 OL	97He-3 O_2	
17 2/3	30 OL	97He-3 O_2	
18	20 OL	97He-3 O_2	Dr. Alexander arrives at 20 feet. Hold for 4 3/4 minute
22	200 IL	Air	Diver switches to air: One rap to vent. Purge 11 with air
22 3/4	20 OL	Air	Start Dr. Alexander to 10 feet.
23	10 OL	Air	Dr. Alexander arrives at 10 feet. Hold for 5 minutes.
24	200 IL	Air	Stop air purge; start final communication tests.
28	10 OL	Air	Start Dr. Alexander to surface
29	0 OL	Air	Dr. Alexander arrives on surface.
31	200 IL	Air	Stop communication tests: Prepare for ascent to 1st stop.

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13. ABSTRACT

The purpose of this study was to evaluate the effect of breathing hydrogen on the intelligibility of speech. Taped recordings were made of a talker breathing normal air within 1 atmospheric pressure absolute (ATA) and also breathing hydrogen, helium and air at 7 ATA. Responses to the recordings by six panels of listeners were analyzed. As expected, the speech in air at 1 ATA was the most intelligible, and the speech in air at 7 ATA was next best. There was no appreciable difference in mean intelligibility between the helium and hydrogen gas mixtures. These results indicate that any decision in favor of using either hydrogen or helium mixtures in deep sea diving should not depend upon differences in intelligibility of unprocessed helium - versus hydrogen-speech.

14. KEY WORDS	LINK A		LINK B		LINK C	
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Speech Intelligibility						
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Divers' Speech						